AN IMPROVED SPECTROPHOTOMETER FOR SOIL-WATER MEASUREMENT

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ILLUSTRATIONS

AN IMPROVED SPECTROPHOTOMETER FOR SOIL-WATER MEASUREMENT

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ABSTRACT

The improved spectrophotometer developed offers 1 percent or better accuracy, high sensitivity, and stability over widely varying ambient temperatures. The optical system consists of an infrared source, a chopper, a lens system, a wavelength filter, a sample cell, and a detector. Integrated circuits powered by mercury batteries are used to boost the detector signal to required levels. The electronics amplifiers are contained on a printed circuit board. On the detector board are mounted a lead sulfide (PbS) detector and a PbS temperature-compensation detector. The lens system is contained within a brass assembly. The front panel is used for mounting the lens system, indicating meter, and controls. The printed circuit board, batteries, and a battery charger are housed in the instrument case. This portable, rechargeable spectrophotometer reduces the time required to determine soil-water content, has proven to be stable and reliable, and costs only about $400 (February 1976). A parts list and instructions for calibrating and using the instrument are included. **KEYWORDS: infrared spectrophotometry, photometry, soil water, soil-water measurement, spectrophotometric measurement of soil water, spectrophotometry.**

INTRODUCTION

A problem for researchers who constantly need to know soil-water content is the 24- to 48-hour delay involved with the gravimetric method. Soil-water content can also be determined by the 1.94-μm near-infrared absorbance of soil-water–methanol extracts. Bowers and Smith have shown that this method gives a linear relation between absorbance and percentage of soil-water-content ranges up to 30%.[2] A curvilinear relation may be preferable at soil-moisture ranges exceeding 30%. Although this method requires much less time, approximately 15 minutes, the near-infrared instrument required is expensive, that is, several thousand dollars. Such a cost has placed available units out of reach of many researchers.

Subsequently, Bowers, Smith, Fisher, and Miller demonstrated that an economical spectrophotometer sufficiently sensitive for soil-water measurements could be built.[3] However, this instrument was unstable, had considerable needle bounce, and lacked a precise zeroing capability (resulting in a Y-axis intercept). The new spectrophotometer we have developed eliminates these earlier disadvantages. The improved version offers 1 percent or better accuracy, high sensitivity, and stability over wide-

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[2] Bowers, S.A., and Smith, S.J. 1972. Spectrophotometric determination of soil water content. Soil Sci. Soc. Am. Proc. 36: 978–980.

[3] Bowers, S.A., Smith, S.J., Fisher, H.D., and Miller, G.E. 1975. Soil water measurement with an inexpensive spectrophotometer. Soil Sci. Soc. Am. Proc. 39: 391–393.

ly varying ambient temperatures. Both the electronic circuitry and lens system have been simplified, and costs have been reduced.

INSTRUMENT DESIGN

A satisfactory optical system requires an infrared source, a chopper lens system, a proper wavelength filter, a sample cell, and a detector.

The infrared source is a small tungsten lamp that is usable at wavelengths from visible up to approximately 3 μm. The lamp assembly contains an optical lens, number 1, which is an integral part of the envelope.

A 420-Hz chopper was installed between the lamp and the succeeding lens, number 2. The chopped beam from the lamp is inverted between lenses number 2 and number 3, then passes through a 1.94-μm-wavelength, 0.1-μm-bandwidth filter. Passband characteristics of this filter are shown in figure 1. The 1.94-μm beam is passed through a 1-cm-path sample cell and onto the lead sulfide (PbS) detector.

Because the output-voltage swing of the PbS detector is small, only a few microvolts, an amplifier with high stability and low noise capabilities is necessary to boost the signal. High-reliability integrated circuits were selected for low thermal drift, low noise, and high-gain potentials. Values of the signal-coupling

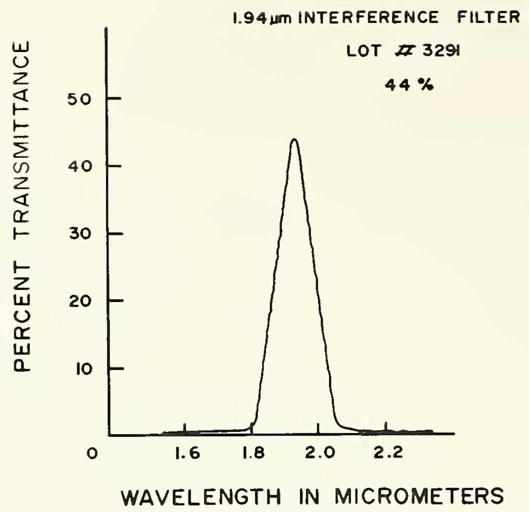

FIGURE 1.—Filter passband.

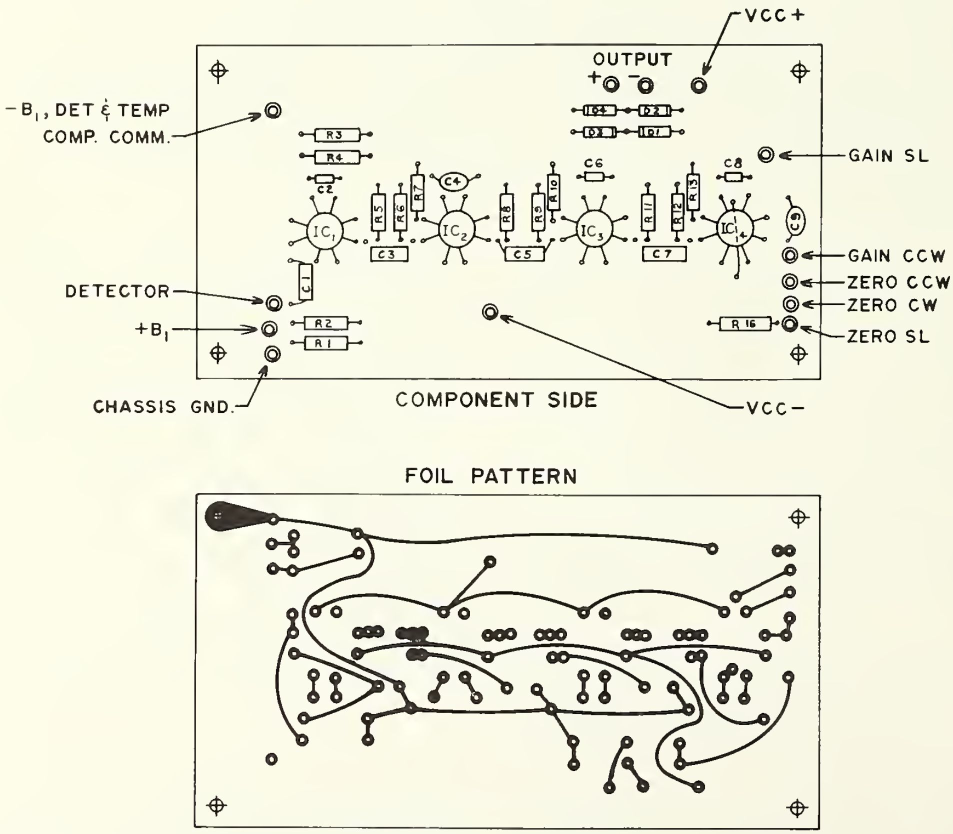

FIGURE 2.—Infrared soil-water-meter printed circuit board.

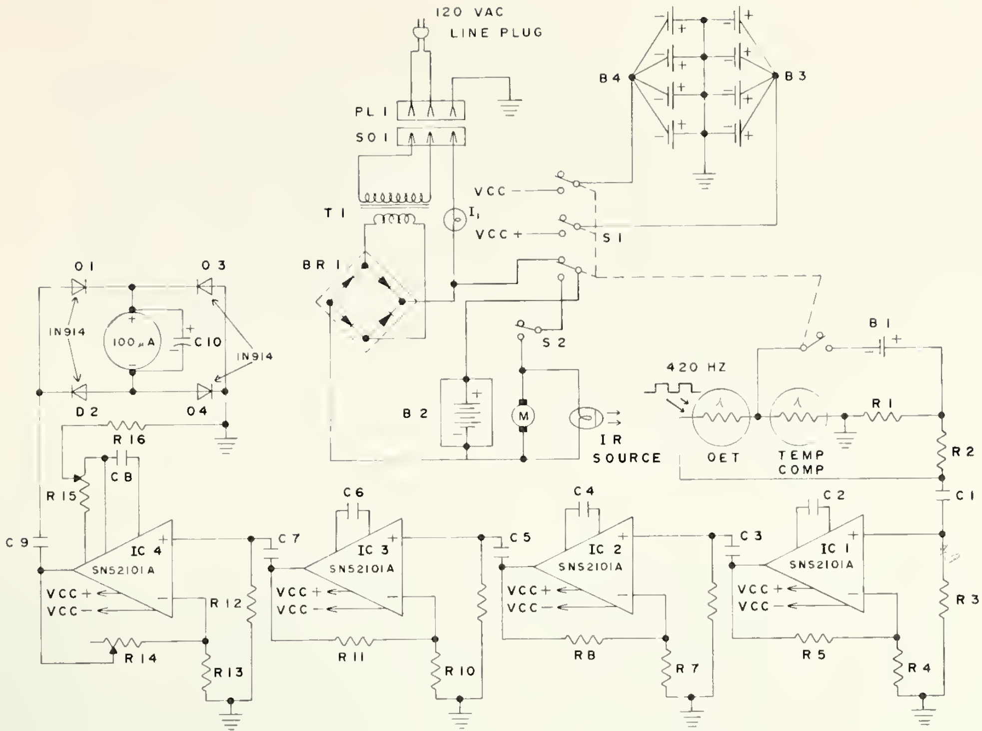

FIGURE 3.—1.94-μm infrared soil-water-meter schematic.

capacitors were chosen for optimum gain and noise limiting factors. A stray powerline frequency of 60 Hz is often difficult to eliminate from low-level amplifiers, but the frequency passband can be adjusted on integrated circuits having an external frequency-compensation capability, filtering most of the unwanted frequencies. Noise peaks and the thermal drift of the integrated circuits have been suppressed by the coupling capacitors and the bandpass characteristics of the frequency-compensation capacitors. The output from the final amplifier is rectified and filtered to provide a noise-free d.c. signal across the indicating meter.

Mercury batteries power the amplifier assembly and supply the detector bias voltage. A 6-volt wet-cell battery powers the chopper motor and source lamp. A small battery charger with a 350-mA charge rate is incorporated into the instrument.

CONSTRUCTION

Electronics Fabrication

The electronic amplifiers are contained on a 3- by 6-in printed circuit board (fig. 2), constructed of fiberglass to eliminate circuit breakage. All components of the amplifiers are soldered to the circuit board foil pattern. The spectrophotometer schematic shows the interconnections (fig. 3). Solder terminals are used as tie points for connecting wiring to components and assemblies not mounted on the circuit board.

The PbS detector and PbS temperature-compensation detector are mounted on the detector board with silicone rubber. A 1-cm square of 2.0-mm-thick fiberglass board is bonded over the face of the PbS temperature-compensation detector, and the PbS detector is placed on the 1-cm-square board directly over the position of the PbS temperature-compensation detector, effectively shielding the PbS temperature-compensation detector from direct infrared radiation. The detector assembly is mounted in the chamber as shown in figure 4.

Lens-System Fabrication

The lens system (fig. 5) for an infrared instrument must focus the infrared beam, as well as shield extraneous infrared sources. The optics of this instrument are contained within a brass assembly (fig. 6). Both interior and exterior surfaces of the brass lens-holder as-

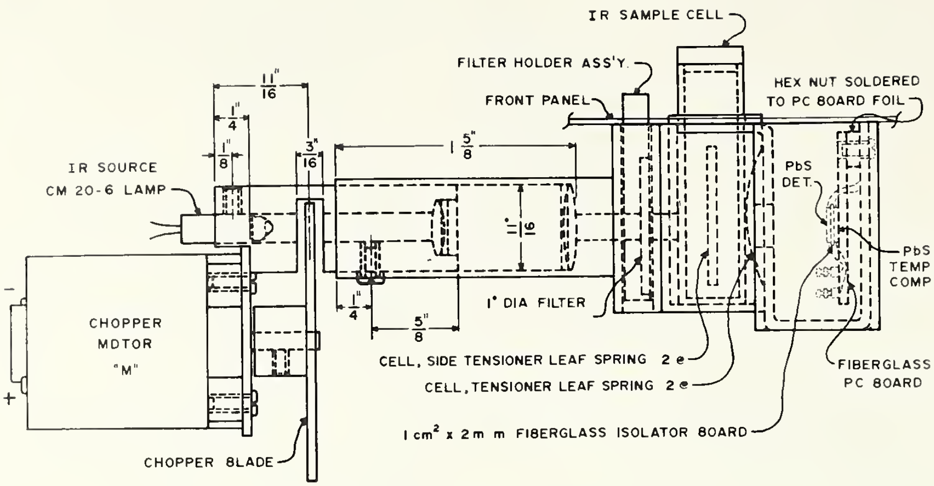

FIGURE 4.—Lens system and chopper.

sembly are painted with a quick-drying flat black paint containing 50% carbon black and 50% silicates, available at most Krylon paint dealers (type number 1602 Krylon).

The lampholder and lens barrel are machined from 1-in brass round stock. Lathe machining of these components is necessary to insure correct alinement of the lens elements.

The filter compartment, sample holder, and detector chamber are constructed of brass stock as shown in figure 6. The assemblies of the lens system are bonded together with silver solder.

The chopper motor is mounted, by means of a brass L-shaped bracket, onto the lampholder. The chopper blade (fig. 6) is machined from 2-in-diameter brass round stock. Openings are drilled (12 holes on a 30° center), and the outer perimeter metal is removed, leaving a U-shaped slot. All burrs should be removed from the slot edges, and all slots should be uniformly shaped and spaced.

The lens system may be adjusted prior to mounting the unit in the enclosure. Remove the filter and connect a 6-volt-d.c. supply to the lamp; place the lampholder in the position that concentrates a round, sharply focused spot of light on the PbS detector; lock the lampholder in this position, completing the initial alinement procedure.

Final Assembly and Alinement

The front panel is used for mounting the lens system, indicating meter, and controls. The panel must be drilled, and openings must be cut to accept the respective components (fig. 7). The printed circuit board, batteries, and battery charger are mounted in the instrument case (fig. 8). A service loop is left in the connecting wiring between the case-mounted components and front panel assemblies.

Upon completion of component mounting and wiring, the main power switch should be turned on to check the amplifier output. The output to meter M1 should be zero. An indication of either + or — output on M1 indicates a wiring error or a defective component. Should the zero output check, turn on the chopper and lamp switch. An upscale indication of meter M1 should be observed. If no indication is present, increase the gain to achieve an upscale indication. Insert the 1.94-μm filter into its holder and increase the gain until M1 indicates midscale. Check the positioning of the filter by slowly moving it inside its holder to determine if the output varies. The proper position corresponds with the maximum output to M1. The

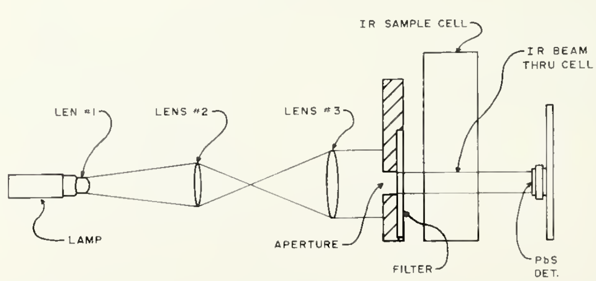

FIGURE 5.—Lens system.

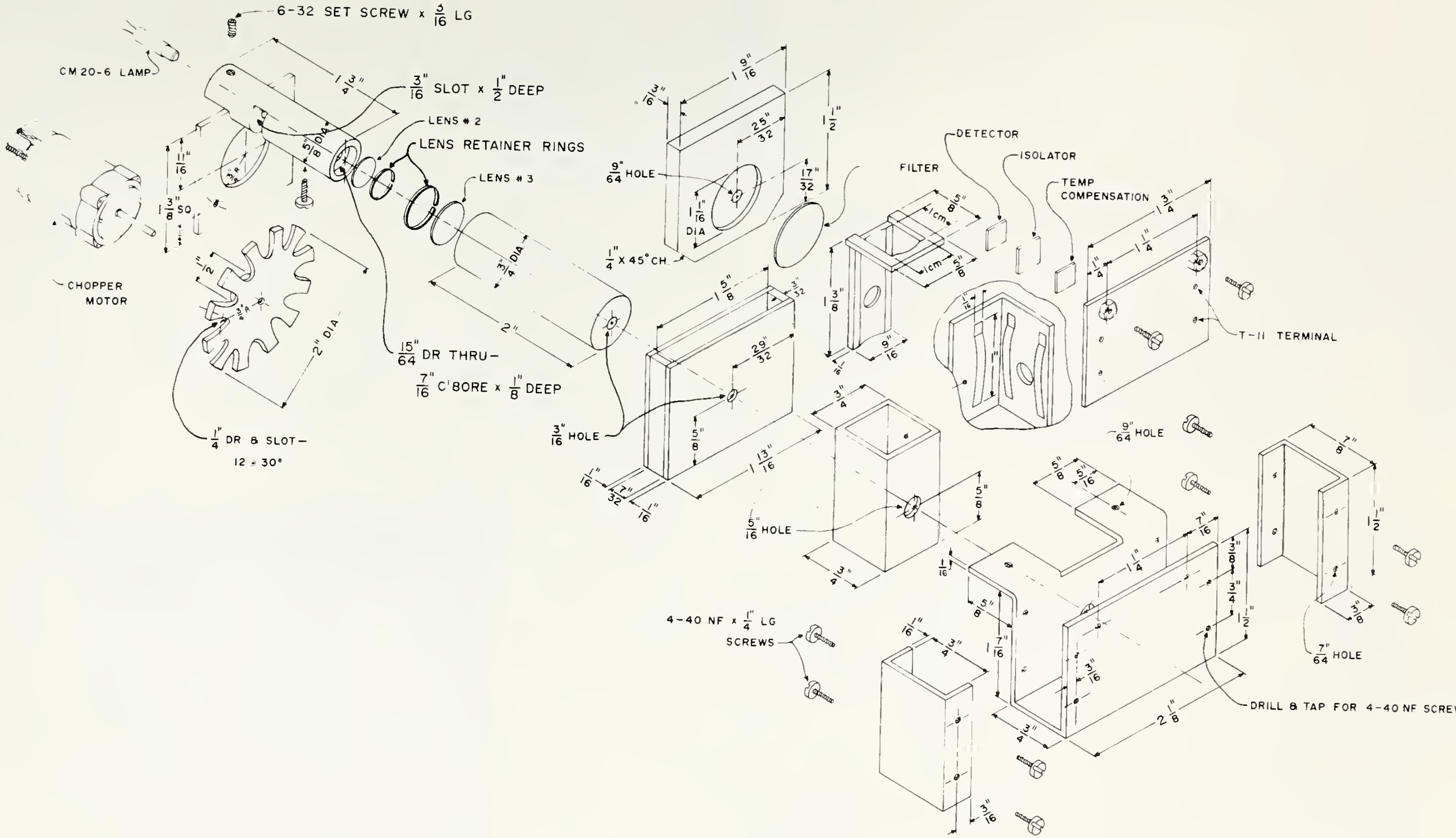

FIGURE 6.—Lens-system component parts.

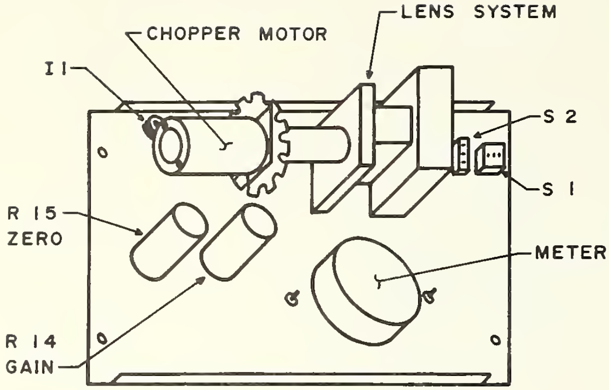

FIGURE 7.—Front panel, rear view.

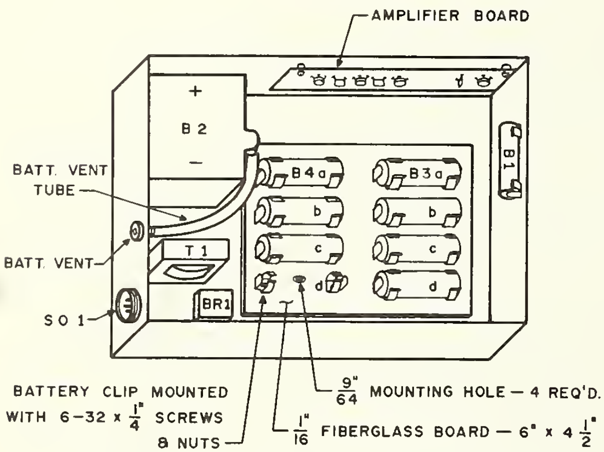

FIGURE 8.—Instrument case, interior view.

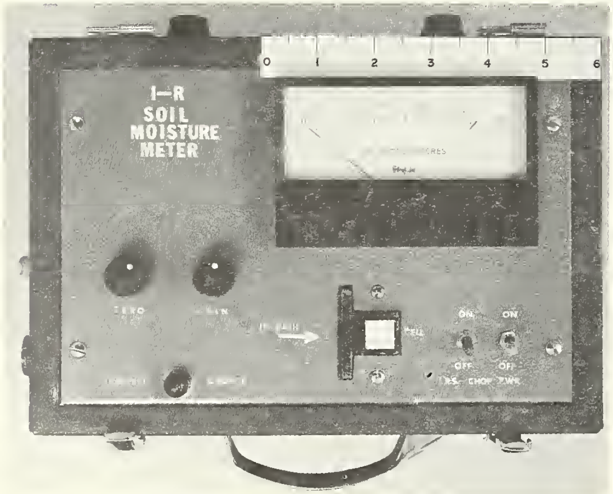

FIGURE 9.—Completed instrument.

filter assembly should be bonded in place with a G.E. silicone rubber. The completed instrument is shown assembled in figure 9.

INSTRUMENT USE

Fill a clean sample cell of the type listed in the appendix with methanol absolute. Insert the cell into its holder and increase the gain to give a full-scale meter indication, 100% *T*. Normally 100% *T* should be achieved with the gain control in its midpoint of adjustment. This completes the adjustments, and the instrument should be checked for calibration with water-methanol standards. The absorbance curve of the standards should conform to the standard curve in figure 10. Soil-water samples to be measured on this instrument should be prepared according to the method given by Bowers and Smith.

APPENDIX.—PARTS LIST

Symbol	*Quantity*	*Part number or type*
. . .	1	Bud transicase TC–300 ($31.20).
IC 1–4	4	SN52101A Texas Instruments operational amplifier.
R1,2	2	77-kΩ, 1%, 0.5-watt film resistors.
R3,16	2	1-MΩ, 1%, 0.5-watt film resistors.
R4	1	220-Ω, 1%, 0.5-watt film resistor.
R5	1	100-kΩ, 1%, 0.5-watt film resistor.
R6,7,9–13	7	2.2-kΩ, 5%, 0.5-watt film resistors.

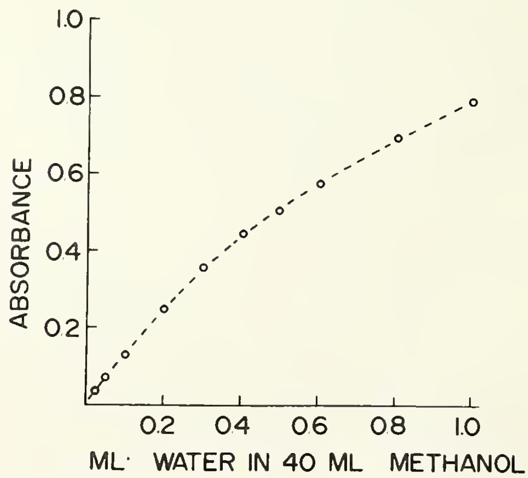

FIGURE 10.—Calibration curve.

Symbol	*Quantity*	*Part number or type*
R8	1	10-kΩ, 1%, 0.5-watt film resistor.
R14	1	50-kΩ, 10-turn pot.
R15	1	100-kΩ, 10-turn pot.
C1,3,5	3	0.10-μF, ceramic-disk capacitors.
C2,6,8	3	100-pF, ceramic-disk capacitors.
C4	1	0.0022-μF, ceramic-disk capacitor.
C7	1	0.22-μF, ceramic-disk capacitor.
C9	1	0.02-μF, ceramic-disk capacitor.
C10	1	350-μF, tantalum capacitor.
Det., Temp. Comp.	2	B3–SA7–17 lead sulfide detectors (Infrared Industries, $20.00 each).
D1–4	4	1N914 diodes.
Br1	1	S–3262 rectifier bridge (Sarkes Tarzian, Inc.).
T1	1	Filament transformer F–14X (Triad).
M	1	Globe permanent magnet motor, #235A150–7, type CMM ($41.00).
B3&B4	8	H–289 mercury batteries, 12.6-V.

Symbol	*Quantity*	*Part number or type*
B1	1	H133 mercury battery, 4.2-V.
B2	1	6N4–2A wet-cell battery, 6-V. (Yuasa Battery Co. Ltd., Japan).
IR source	1	Chicago miniature CM20–6 lamp.
Meter	1	100-μA, 4.5-in, panel meter (Simpson #15089).
S1	1	4PDT miniature toggle switch.
S2	1	SPST miniature toggle switch.
I_1	1	Pilot lamp assembly and 6-V lamp #328.
PL1,SO1	1	3-conductor cannon plug and matching chassis socket.
. . .	1	Line cord, 3 conductor, 18-gage) vinyl with molded line plug.
. . .	1	1.94-μm filter with 0.1-μm bandwidth (Optics Technology, Inc., #3290, $85.00).
Lens 2	1	Lens #94188, double convex diameter: 10 mm–FL 13 mm (Edmond Scientific).
Lens 3	1	Lens #94673, double convex diameter: 13 mm–FL 58 mm (Edmond Scientific).
. . .	1	1I10 infrared sample cell, match code 5.1 (Markson).

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